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Influence of Long-Term Oven Aging Laboratory on Tensile Strength of Porous Asphalt Containing PET Waste and Modified Natural Asphalt

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Abstract:

In recent years, many potential alternatives in pavement engineering related to plastic asphalts have been studied to decrease plastic waste. One promising recycling alternative is to adopt plastic waste of Polyethylene Terephthalate PET bottles in the asphalt pavement construction, including porous asphalt mixture. Modified Buton asphalt (MBA) is a bituminous material made by combining the bitumen extracted from the natural rock asphalt and petroleum bitumen. MBA was used as bituminous material to produce porous asphalt mixture without PET and PET in this study. As part of continuous research on the production of MBA-plastic waste-based asphalt mixture, this paper reported the influence of long-term aging laboratory on indirect tensile strength of porous asphalt mixture without PET waste and that containing PET waste. After long-term aging treatment completion, in terms of indirect tensile strength value, specimens with 0.5% of PET waste were higher by 1.28 times than the no PET specimens. In contrast, on average, the horizontal strain value of samples with 0.5% of PET waste was almost similar to the no PET specimens.

Keywords: Long-Term oven aging, Tensile strength, PET waste, Modified natural asphalt

I. INTRODUCTION

Most parts of Indonesia have high-intensity rainfall; hence, puddles will arise on the roads covered with impermeable surfaces such as the dense asphalt mixture for a few moments. When a vehicle passes in a puddle of water, aquaplaning will occur, thereby reducing the grip of the tires to the road surface, and there will also be splash of water. Aquaplaning and water splashing will negatively affect traffic smoothness and endanger motorists. To reduce aquaplaning and water splashing, one effort is to use porous asphalt as a wearing layer or surface layer of the road [1, 2].

In the southern region of Buton Island, Southeast Sulawesi province, Indonesia several areas have a land surface covered by bitumen that has bonded with limestone sediments to form natural asphalt rock known as Buton rock asphalt (BRA). Many BRA purification processes have succeeded in extracting bitumen from limestone sediment. Among the results of BRA refinery is liquid Buton asphalt, which still contains about 30% sediment and 70% bitumen. Buton asphalt is often summarized as Asbuton (asphalt Buton) so that liquid Buton asphalt is referred to as liquid asbuton. A study conducted by Tjaronge et al. has shown that the performance of liquid asbuton liquid-based porous asphalt met the technical specifications of porous asphalt mixture [3].

In addition, there is an enrichment process in which bitumen extracted from BRA is mixed with petroleum asphalt to produce modified Buton asphalt (MBA). In order to support the traffic of people and goods, the land transportation network needs to be developed efficiently by using local natural resources. In connection with this effort, this study uses MBA as a bituminous material to manufacture porous asphalt. This study used MBA produced by Indonesian company of natural rock asphalt refinery that processes BRA. The MBA used in this research can be obtained easily in the market and widely known as the refinery Buton asphalt (Retona) blend. The use of MBA in the form of Retona blend for dense asphalt mixture shows that the performance related to technical specifications for volumetric can be achieved satisfactorily [4,5,6].

In recent decades, excessive use of plastics including Polyethylene Terephthalate (PET) that is used as soft drink bottles has led to overburden piles of plastic waste in the landfill. The continuous disposal of plastic waste can cause serious environmental problems as well as severe health threats to the landfill. Serious and intensive efforts have been conducted to reuse plastic waste including PET waste hence can decrease the generation of plastic waste, also environmental damage and health level reducing can be avoided. A number of experimental studies have shown that PET waste can be used to improve the performance of asphalt mixtures [7,8,9].

It has been prevalent knowledge for engineers and scientists working in pavement engineering that there are two phases of aging that occur in asphalt mixtures, namely short-term aging and long-term aging. Volatilization that occurs during heating, mixing, and spreading is a process that causes the hardening of the asphalt mixture which is short-term aging. After finishing the process of spreading, the compacted asphalt mixture hardens due to oxidation during its service life which is long-term aging [10]. In this regard, it is imperative to predict an asphalt mixture's long-term and short-term aging so that an asphalt mixture based on durability in terms of aging can be made.

Fig. 1 shows the behavior of each layer of multi-layered road construction. When a vehicle load is above the surface layer, each layer in the top area will experience compressive stress, and the bottom part will experience tensile stress. The illustration in Fig. 1 shows a road construction with a wearing course made of porous asphalt mixture, and the second layer is impermeable. Long-term aging influences the wearing course, so it needs to be analyzed as early as possible. Artificial long-term aging in the laboratory can be used to simulate aging conditions in the field [11].

The test results reported in this paper are part of a series of laboratory tests to enrich knowledge about the use of PET waste with MBA to manufacture porous asphalt. Several physical properties of porous asphalt containing PET waste and MBA have been reported in previous studies [12,13]. Based on the results of research conducted by Mabui D. S. et al., 2020 [14], this study used PET waste together with MBA to produce porous asphalt also, specimens without PET were made as a reference then used laboratory oven aging procedure as artificial aging that simulates long-term aging. In addition, an indirect tensile strength test was carried out on porous asphalt specimens that had experienced long-term aging in the laboratory.

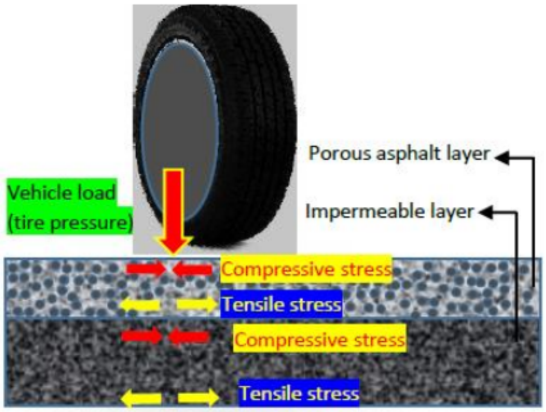

Fig 1: Behavior of multi-layered pavement subjected to a vehicle load

II. MATERIALS AND METHOD

A. Modified Buton Asphalt

Table 1 shows the physical properties of MBA (Retona blend).

TABLE I Properties of MBA

No.	Property	Value
1	Penetration before weight loss (mm)	78.6
2	Softening point (°C)	52
3	Ductility in 25°C, 5cm/minute (cm)	114
4	Flash point (°C)	280
5	Specific gravity	1.12

6	Penetration after weight loss (mm)	86

B. Polyethylene Therepthalate (PET)

Polyethylene terephthalate (PET) is a thermoplastic polymer made by the chemical industry and has a high melting point of 260^0C [15]. In order to use as an additive in the porous asphalt mixture, PET-based disposable bottles collected from domestic waste were shredded to pass sieve no.4 and retained in sieve no. 50. Fig. 2 shows the waste PET and shredded PET waste that used in this study.

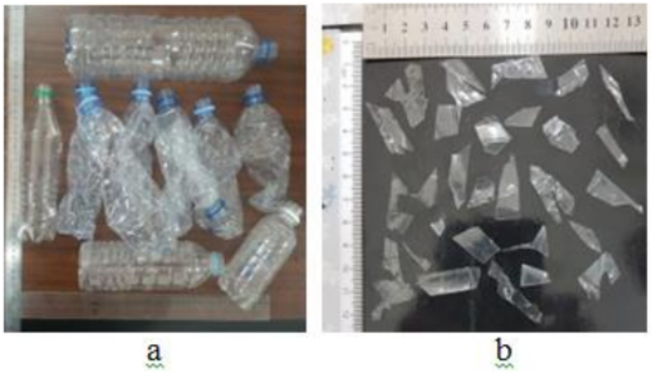

Fig 2: (a) The waste PET and (b) shredded PET waste

C. Coarse Aggregate and Stone Dust

Two fractions of crushed river stone were used as coarse aggregate, viz coarse aggregate with diameter 5-10 mm and diameter 10-20 mm, respectively. Coarse aggregate diameter of 10 – 20 cm had water absorption of 2.08%, saturated surface dry density of 2.68, and an abrasion of 24.36%, respectively. Coarse aggregate diameter of 5 – 10 cm had water absorption of 2.07%, saturated surface dry density of 2.67, and abrasion of 25.72%, respectively. The stone dust obtained from the river rock crushing process was used as fine aggregate and filler in a small amount to prevent bleeding and drain the porous asphalt mixture. Stone dust (fine aggregate pass sieve No. 8 and retained on sieve No. 200 (0.075 mm)) is used as fine aggregate in this study had a water absorption of 2.79%, saturated surface dry density of 2.52, and sand equivalent of 89.66%, respectively. Stone dust that is used as filler (pass sieve no. 200) in this study had water absorption of 2.28% and a saturated surface dry density of 2.65, respectively.

TABLE II Mixtures design of porous asphalt with and without PET waste

No.	Materials	Unit	Mixture without PET waste	Mixture containing PET waste
A	Modified Buton asphalt	%	6	6
	Modified Buton asphalt	gr	72	72
B	Plastic Waste Content	%	0.0	0.5
	Plastic Waste	gr	0.00	5.64
C	Coarse aggregate and stone dust			
	Sieve			
1	3/4 “	gr	-	-
2	1/2"	gr	28.70	27.76
3	3/8”	gr	478.95	478.01
4	No.4	gr	451.15	450.21
5	No.8	gr	56.40	55.46
6	No.200	gr	73.66	72.72
7	PAN	gr	39.14	38.20
Total C1-7		gr	1128.00	1128.00
D	Sample weight	gr	1200.00	1200.00

D. Porous Asphalt Preparation

The preparation of specimen containing waste PET and that without PET are as follows:

1. The mixture of aggregates and filler was heated to 160°C for an hour.
2. The MBA was heated up to 150°C.
3. For mixture with PET, at the same time PET waste was heated up to 150°C.
4. For mixture with PET, the combination of aggregate, filler, MBA and PET that have been formulated was mixed at a temperature of 150°C until entire aggregates were uniformly covered by the mastic asphalt. Likewise, for the mixture without PET, the combination of aggregate, filler and MBA that have been formulated was mixed at a temperature of 150°C until the asphalt mastic uniformly covered the entire aggregates.
5. Short-term aging treatment was given to both of the loose mixtures prior poured and compacted in the mould. A method of curing the loose mix in a forced oven at 135°C for 4 hours was used as short-term aging. All mixtures experienced short-term aging laboratory.

6. After short-term aging treatment completion, a loose mixture was poured and compacted in the mould at a temperature of 135°C.
7. Long-term aging treatment was given to all specimens. Oven aging at 85°C for 4 days was used as long-term aging laboratory.

E. Indirect Tensile Strength Test

Fig. 3 shows the mechanism of the indirect tensile strength test carried out in this study. Fig. 4 shows the displacement that occurs in the specimen that experiences a tensile load. The specimen was placed on its back, and compressive load was induced along the side until the specimen failure with the split pattern. A load cell was used to measure the load received by the specimen. A universal testing machine (UTM) was used for testing the specimen of porous asphalt. The split tensile stress is determined using Equation 1. On each side right in the middle of specimen, an LVDT was installed to measure the horizontal deformation that occured due to the load received by the specimen. The combined deformation values obtained from measurements using two LVDTs divided by the diameter of the specimen is the horizontal strain value as shown in Equation 2. Data acquisition devices were linked to load cell and LVDTs that record and monitor loads and displacements.

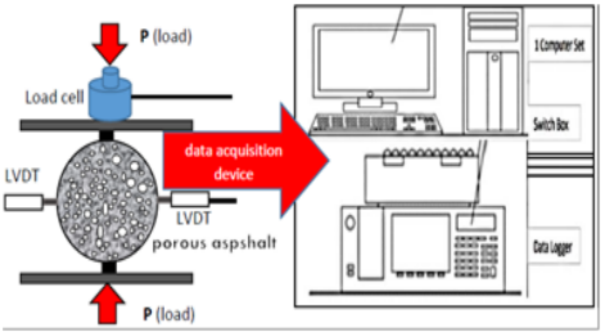

Fig 3: The mechanism of tensile strength test

$$\sigma = \frac{2P}{\pi.\ d.\ t} \qquad (1)$$

Where:

σ = maximum stress component in the x direction on the vertical line (MPa)

P = applied vertical load (N),

d = diameter of the specimen (mm)

t = thickness of the specimen (mm)

$$\varepsilon_H = \frac{\Delta 1 + \Delta 2}{d} \qquad (2)$$

Where:

ε_H = horizontal strain (mm/mm),

$\Delta 1$ = displacement of the right part of the specimen (mm)

$\Delta 2$ = displacement of the left part of the specimen (mm)

d = diameter of the specimen (mm)

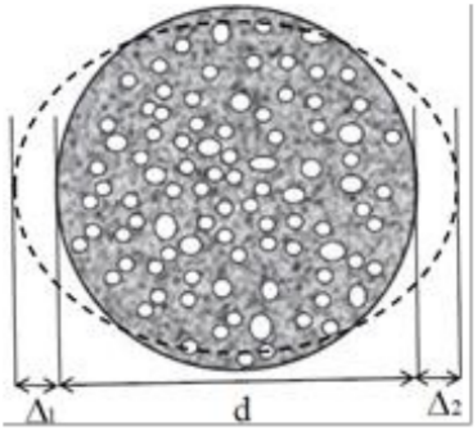

Fig 4: Displacement of specimens

III. RESULTS AND DISCUSSION

A. Physical Appearance

Table 3 shows the effect of aging on the physical appearance of the test object. After short-term aging compleition, observation was conducted on specimens that had just been compacted and removed from the mould.

TABLE III Effect of aging on the physical appearance of the test object

Compacted specimens (Ø101.6 × 67 ± 5 mm)	After short-term aging completion	After long-term aging completion
Without waste PET	No visible cracks	No visible cracks
	All coarse aggregate covered by membrane	No visible loose coarse aggregate
With waste PET	No visible cracks	No visible cracks
	All coarse aggregate covered by membrane	No visible loose coarse aggregate

The visual observations on the compacted specimens showed no piling of bitumen, PET, and filler in a specific area within the specimens. No visible bleeding of exessive bitumen and no cracking due to over-compacting. There was a membrane layer attributed from the arrangement of MBA and PET, where the membrane layer coated the coarse aggregate. These results indicated that MBA and PET were effectively mixed. A rearrangement that occurred in MBA and PET at the time of mixing formed a stable asphalt mastic. The compaction process took place perfectly, resulting in the coarse aggregate particles firmly bonded by the membrane layer.

After long-term aging completion, observation was conducted on specimens that had just been removed from the oven. The results of visual observations showed that there was no cracking due to excessive hardening and no separation between MBA and PET. These results indicate that MBA and PET with different melting temperatures have achieved uniform mixing; hence the long-term aging process did not separate them.

B. Indirect Tensile Strength

The elastic limit of a material including porous asphalt needs to be considered because this value is the main factor in analyzing the ability to accept loads including tensile loads without being damaged. This study uses a monotonic static load to cause a tensile force on a porous asphalt specimen where one of the results was the relationship between tensile stress and horizontal strain. Therefore, the relationship between tensile stress and horizontal strain is important to observe in determining the elastic limit of porous asphalt.

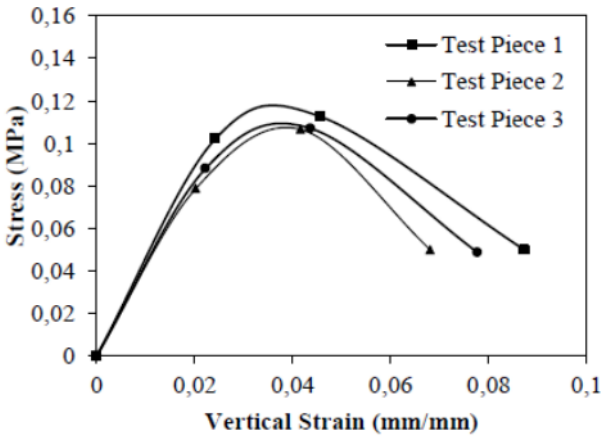

Fig 5: Tensile stress and horizontal strain of porous without waste PET after long-term aging

The relationship between tensile stress and horizontal strain in long-term aging specimens is shown in Fig. 5 specimens without PET) and Fig. 6 (specimens containing PET). For specimens without PET waste as shown in Fig. 5, it is seen that the elastic region is characterized from a linear relationship between stress and strain up to about 50% of the indirect tensile strength value. For specimens containing PET waste as depicted in Fig. 6, it can be stated that the indirect tensile strength with strain formed linear relationship up to about 50% of the indirect tensile strength indicating the elastic region.

Table 3 shows the indirect tensile strength (indirect tensile stress peak) and the associated horizontal strain of the specimens that have received the long-term aging treatment. As can be seen from the Table 3, the no PET waste specimens had tensile strength less than the mixture modified by 0.5% of PET waste. The peak tensile stress of the specimens modified with 0.5% of PET waste increased by about 28.2% compared to the no PET waste specimen, or in other words the ratio of the indirect tensile strength of specimens with PET waste to that of no PET was around 1.28. Whilst on average, specimens with 0.5% of PET waste had similar horizontal strain value with the no PET specimens.

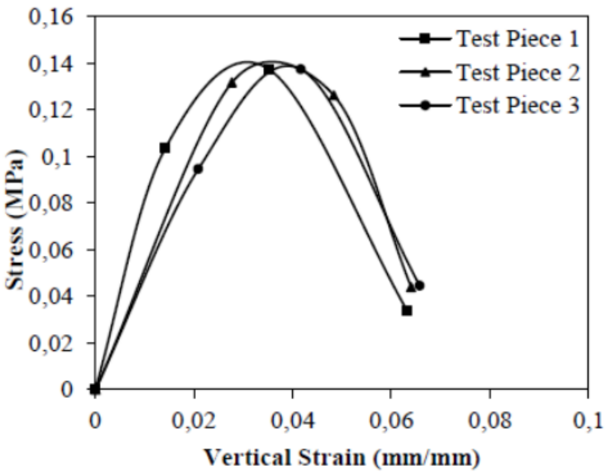

Fig 6: Tensile stress and horizontal strain of porous asphalt containing PET waste after long-term aging

TABLE IV Indirect tensile strength (indirect tensile stress peak) and the associated horizontal strain of the specimens that have received the long-term aging treatment

No. (specimen)	PET waste content (%)	Indirect tensile strength σ (MPa) ($x10^{-3}$)	Horizontal strain ε_H (mm/mm) ($x10^{-3}$)
1	-	112.0	11.97
2		100.0	10.89
3		100.0	11.78
average		104.0	11.54

1	0.5	137.0	9.90
2		126.0	12.04
3		137.0	10.93
average		133.3	10.95

IV. CONCLUDING REMARKS

When MBA containing petroleum bitumen is mixed with PET to produce a porous asphalt mixture, the MBA and PET asphalt undergo re-arrangement, and form a membrane layer that covers the coarse aggregate firmly and can be easily compacted to produce stably connected porous asphalt pores. As a result, a porous asphalt mixture containing MBA and PET has sufficient strength to withstand tensile load after underwent long-term aging. In terms of indirect tensile strength value, it can be reported that the ratio value for specimens with 0.5% of PET waste to the no PET specimens was 1.28. Whereas on average, specimens with 0.5% of PET waste had approximately the same horizontal strain value as no PET specimens.

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